Silicone elastomers with superior softness and dielectric properties

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Silicone elastomers with superior softness and dielectric properties

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Abstract

Dielectric elastomers (DEs) change their shape and size under a high voltage or reversibly generate a high voltage when deformed. The obstacle of high driving voltages, however, limits the commercial viability of the technology at present. Driving voltage can be lowered by decreasing the Young's modulus and increasing the dielectric permittivity of silicone elastomers. One such prominent method of modifying the properties is by adding suitable additives.**[1]** The major drawbacks for adding solid fillers are agglomeration and increasing stiffness which is often accompanied by the decrease of electrical breakdown and achievable strain.**[2]**
In this work, three liquid additives - ***inert silicone oil***, ***chloropropyl-functional silicone oil***, and ***synthesized chloropropyl-functional copolymer*** - were blended into commercial silicone elastomers, and their properties were investigated.
The functional groups were determined by NMR and morphology structures were investigated by optical microscopy. The resulting elastomers were evaluated with respect to their dielectric permittivity, viscoelasticity and tensile strengths, as well as electrical breakdown.

Keywords: silicone elastomer, Young's modulus, dielectric permittivity, electrical breakdown, silicone oil, chloropropyl-functional

Experimental

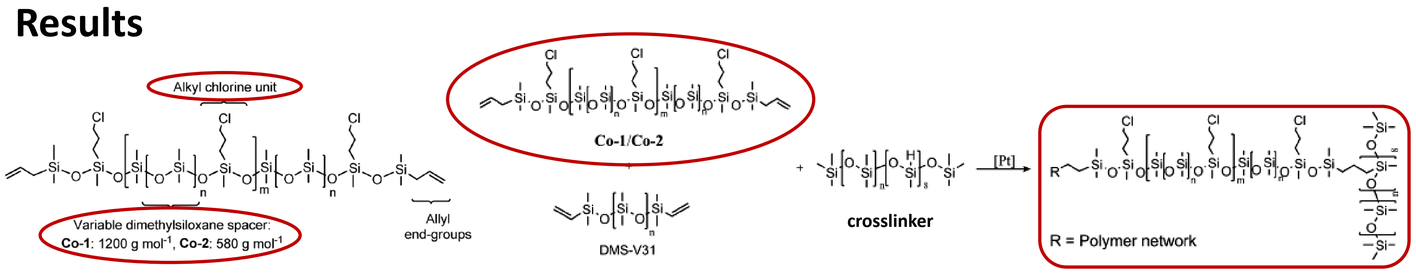
Materials

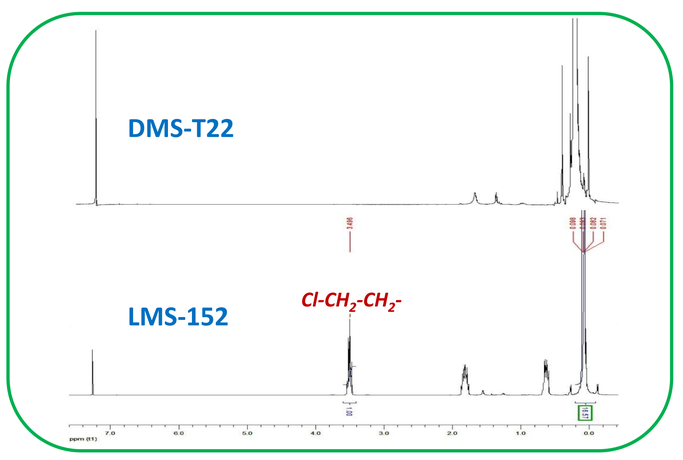
ELASTOSIL® LR 3043/50 A/B: liquid silicone rubber, Wacker Chemie AG, Germany
SiO_2 nanofiller: D50 ~40nm, amorphous, hexamethyldisilazane treated, Fluorochem, Germany
LMS-152 (chloro-oil): [14-16% (chloropropyl)methylsiloxane] - dimethylsiloxane copolymer, 300-450 cSt, Gelest, USA
DMS-T22 (silicone-oil): polydimethylsiloxane, trimethylsiloxy terminated, 200 cSt, Gelest, USA
Co-1: M_w=29000g/mol, copolymer contained alkyl chloride-groups with 1200 g/mol dimethylsiloxane spacers between each group, *self-made*
Co-2: M_w=29000g/mol, copolymer contained alkyl chloride-groups with 580 g/mol dimethylsiloxane spacers between each group, *self-made*
DMS-V31: vinyl terminated polydimethylsiloxane, 1000cSt, Gelest, USA

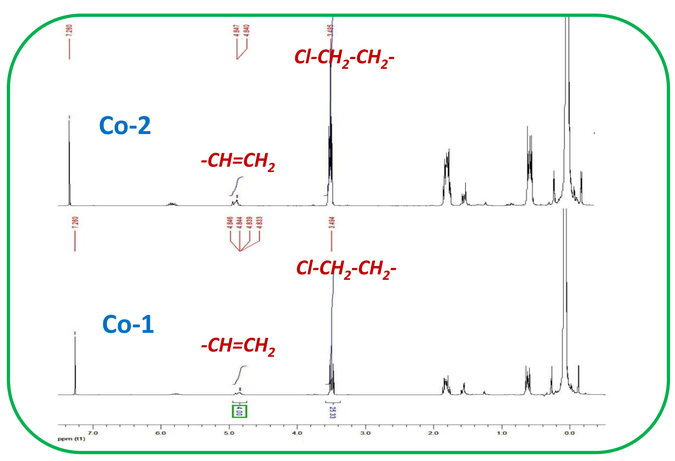
Characterization

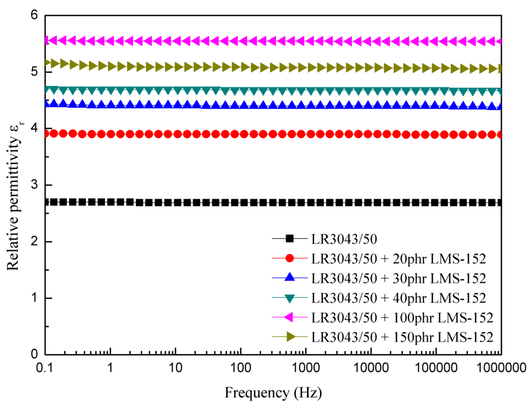
Nuclear magnetic resonance (**NMR**) spectroscopy: chemical structure
Dielectric relaxation spectroscopy (**DRS**): dielectric properties
Electrical breakdown (**BD**): breakdown strength
Optical microscope (**OM**): morphology
Rheometry (**ARES-G2**): mechanical properties

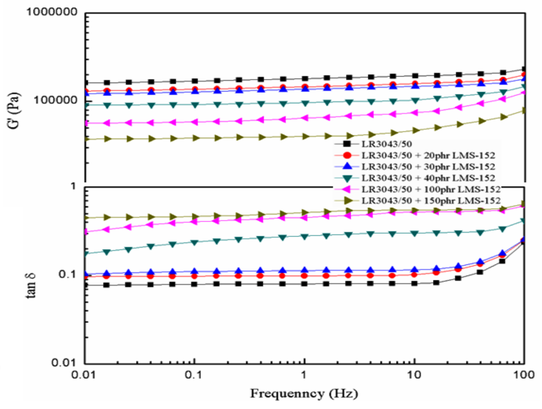
Results

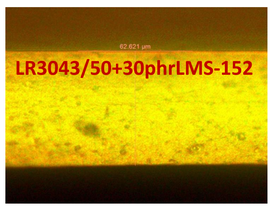












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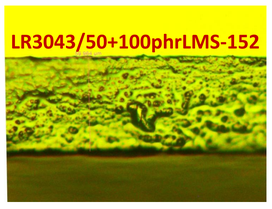
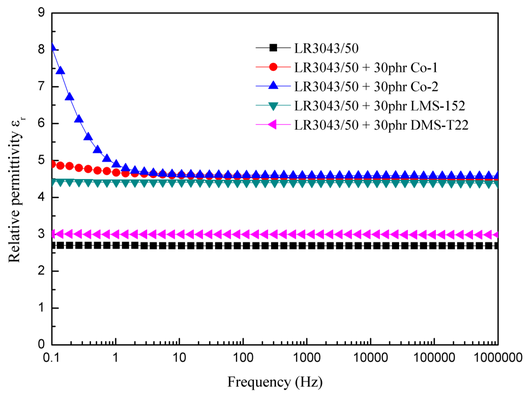
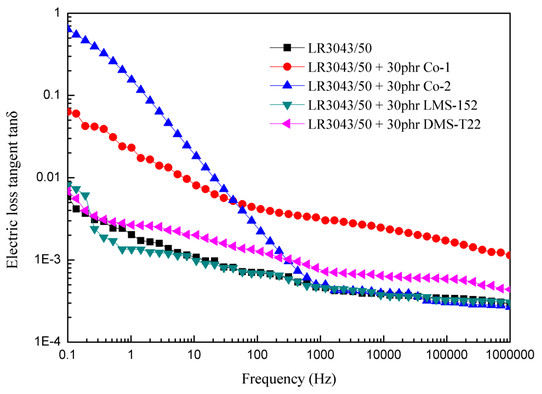


inhomogeneous





No	Composition	Thickness (µm)	Breakdown (V/µm)	Young's modulus @ 5% strain (MPa)	Tensile strength (MPa)	Strain @ break (%)
#0	LR3043/50	49	170	2.41	5.23	717
#1	Co-1 pure + 25 wt% SiO_2	80	66	0.15	0.65	429
#2	Co-2 pure + 25wt% SiO_2	113	69	0.52	1.27	314
#3	LR3043/50 + 30 phr Co-1	75	122	1.90	6.51	596
#4	LR3043/50 + 30 phr Co-2	106	113	2.00	5.06	314
#5	LR3043/50 + 100 phr Co-1	80	83	1.09	1.06	254
#6	LR3043/50 + 100 phr Co-2	129	89	1.29	3.71	256
#7	LR3043/50 + 30 phr LMS-152 (chloro-oil)	78	120	1.73	3.34	481
#8	LR3043/50 + 100 phr LMS-152 (chloro-oil)	96	62	0.60	0.78	269
#9	LR3043/50 + 30 phr DMS-T22 (silicone-oil)	99	98	0.87	4.43	658
#10	LR3043/50 + 100 phr DMS-T22 (silicone-oil)	94	61	0.27	1.51	493

$$F_{om}(\mathrm{DEA}) = \frac{3\varepsilon_r\varepsilon_0 E_{breakdown}^2}{Y} \qquad F_{om}(\mathrm{DEG}) = \frac{\varepsilon_r\varepsilon_0 E_{breakdown}^2}{2\varphi}$$

Figure of merits (F_{om}) to assess elastomer performance as a dielectric elastomer actuator (*DEA*) and a dielectric elastomer generator (*DEG*)

No	Composition	Breakdown (V/µm)	Young's modulus @ 5% strain (MPa)	Relative permittivity ε_r @0.1Hz	Relative permittivity ε_r @1MHz	F_{om}(DEA) @0.1Hz	F_{om}(DEA) @1MHz	F_{om}(DEG) @0.1Hz	F_{om}(DEG) @1MHz
#0	LR3043/50	170	2.41	2.70	2.69	1*	1*	1*	1*
#3	LR3043/50 + 30 phr Co-1	122	1.90	4.90	4.50	1.19	1.09	0.93	0.86
#4	LR3043/50 + 30 phr Co-2	113	2.00	8.06	4.58	1.59	0.91	1.32	0.75
#7	LR3043/50 + 30 phr LMS-152	120	1.73	4.43	4.38	1.14	1.13	0.82	0.81
#9	LR3043/50 + 30 phr DMS-T22	98	0.87	3.01	2.99	1.03	1.02	0.37	0.37

Conclusions

The ***breakdown strength*** increased at low amounts of additives whereas it decreased at larger amounts. The elastomers became increasingly ***soft*** with increasing addition of soft filler. Both inert and chloropropyl-functional silicone oils enhanced the molecular motions of the network substructures via dynamic dilution effects but the ***viscous losses*** also increased with increasing amount of silicone oils. Cross-linkable chloropropyl-functional copolymer offered a high level of mechanical integrity of the blended elastomers thus consequent low viscous losses.
The ***dielectric permittivity*** of chloropropyl-functional blended elastomers increased greatly compared to the pristine commercial elastomer, while the dielectric losses remained at a low level. The increase in dielectric permittivity stemmed from the high dipole moment of the ***chloride*** groups. Furthermore, the alkyl chloride units yielded a larger free volume resulted in a less dense material with a lower ***Young's modulus***.**[3]**

Acknowledgments

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